A Preliminary Assessment of Physical Demand during Simulated Lunar Surface Extravehicular Activities

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HUMAN PHYSIOLOGY, PERFORMANCE, PROTECTION & OPERATIONS

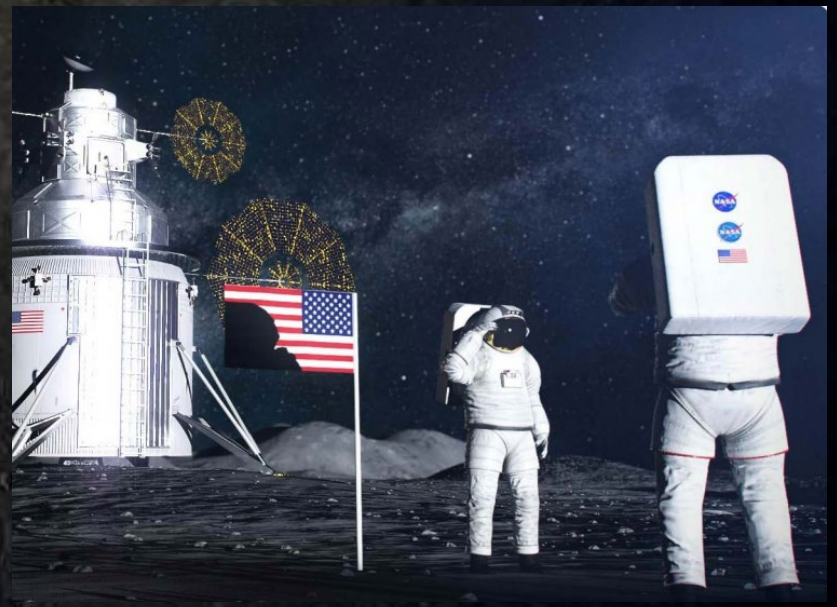
Background

♦ **Returning to the moon requires development of a new exploration spacesuit**

♦ **Artemis astronauts will complete a far more rigorous Extravehicular Activity (EVA) schedule than Apollo and ISS crew**

♦ **Metabolic rates during Apollo EVA were ~50% lower than similar tasks performed in a ground analog environment:**

- limited mobility of the Apollo suit
- increased work capacity enabled by higher mobility space suits
- comparison of nonequivalent flight and ground-test tasks
- compensation for reduced-gravity simulation environments



Motivation

- **The goal of this study is to enable estimation of metabolic rate profiles for expected planetary EVA tasks**
  - Estimated metabolic rate profiles will support human health and performance monitoring and modeling

- **Secondary objectives:**
  - Which functional movements drive changes in metabolic rate
  - Which tasks require crew to be trained with pacing strategies
  - Compare suited work rate outcomes from simulated partial gravity offloading against planned Exploration Prebreathe simulation metabolic rates

Study Design

- **Active Response Gravity Offload System (ARGOS) simulated the lunar environment (1/6thg-offload)**

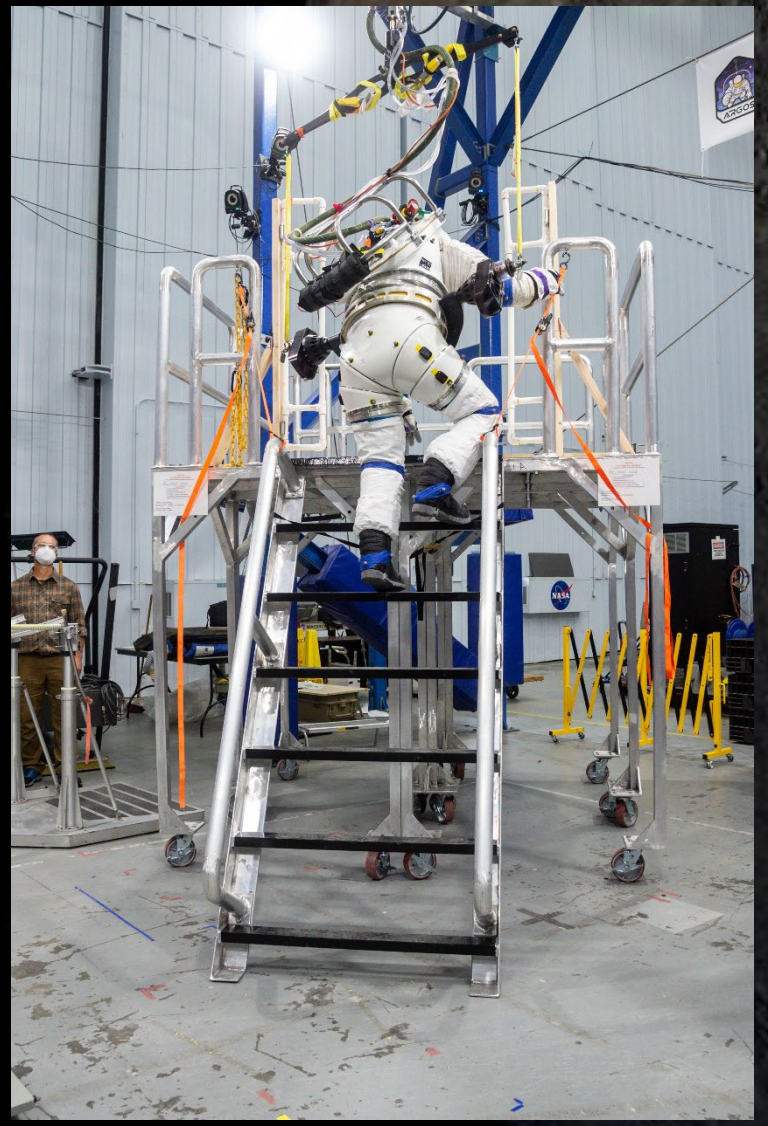
- **Two subjects completed two simulated EVAs**
  - Mark III spacesuit pressurized to 4.3 psid

- **Tasks completed in two blocks**
  - End-to-end (E2E) EVA task block
  - Standalone (SA) task block

- **Collected continuous values of metabolic rate (MR) and heart rate (HR) to assess physical demand**

Task: Lander Operations

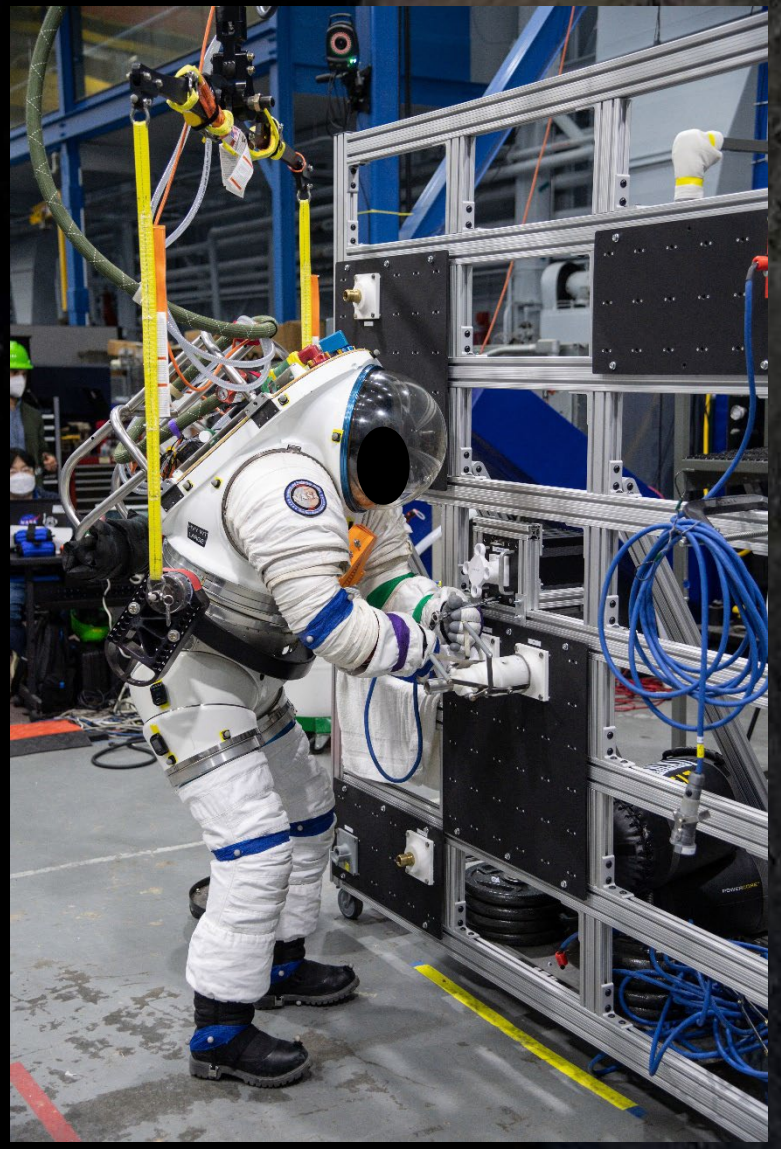
- **Functional tasks:**
  - Transfer from platform to ladder
  - Descend a Ladder
  - Climb a Ladder
  - Transfer from ladder to platform
  - Step Off Ledge
  - Step Up Onto Ledge



Task: Task Board- Cable Routing

- **Task is meant to represent light stationary work and postural challenges**

- **Functional Movements and Tasks Tested:**
  - Operate Switches and Controls
  - Cranking Motion
  - Mate & Demate Umbilical, NZGL Connector, Cannon Connector, Fluid Quick Disconnect Connector, TA Clamp
  - Single Kneel
  - Single Kneel - Single Hand Object Pick-up
  - Single Kneel - Two Hand Object Pick-up
  - Double Kneel
  - Cross-Body Reach
  - Retrieve hardware from high stowage
  - Stow hardware into high stowage



Task: Incapacitated Crew Rescue

- **Demonstrate conceptual operations of loading an incapacitated crewmember (EMU lo-fi mockup) onto a notional incapacitated crew rescue surface transport system by a rescuer crewmember**
  - Allows combined mobility and performance assessment

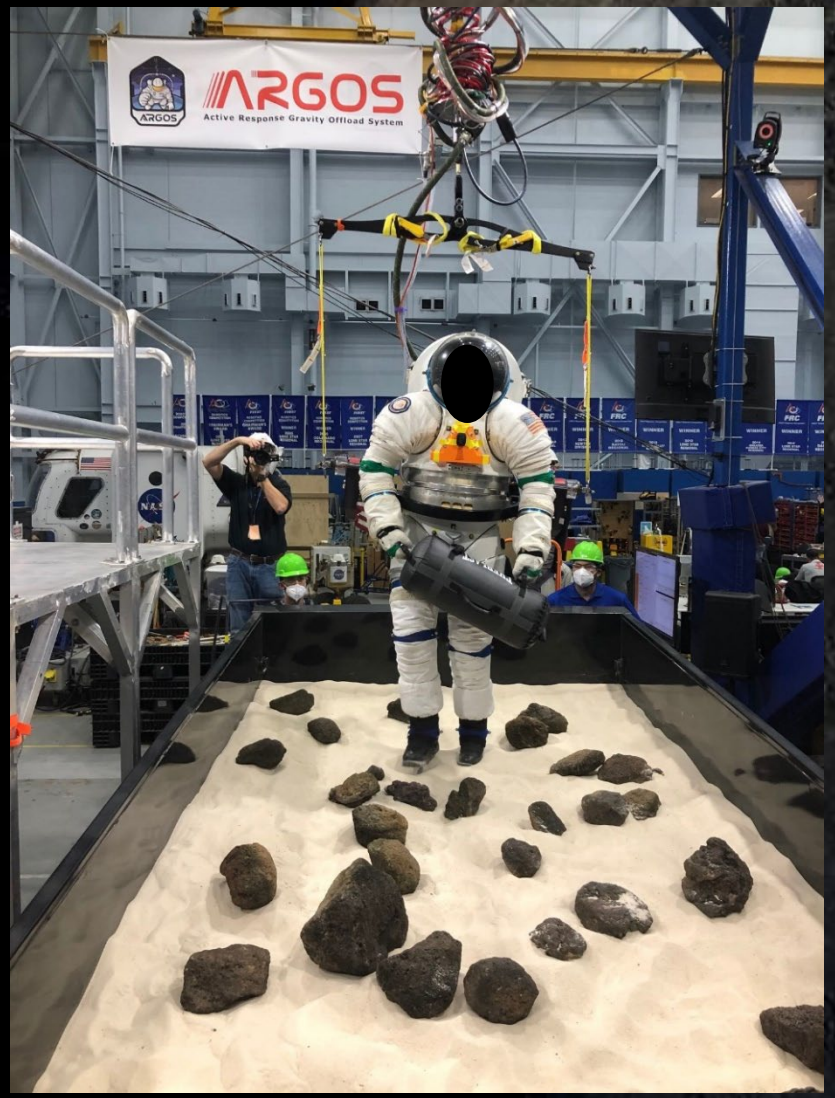
Task: Geology Sampling

- E2E geology will consist of end-to-end sampling beginning at sample marker placement and ending with sample stowage
- SA geology treats each tool as a standalone task for a prescribed amount of time

- Minimum tools/sample types evaluated from mobility requirements:
  - Rake Sampling
  - Float Sampling
  - Rock Chip Sampling
  - Drive Tube Sampling Operation
  - Trenching Operations
  - Camera usage

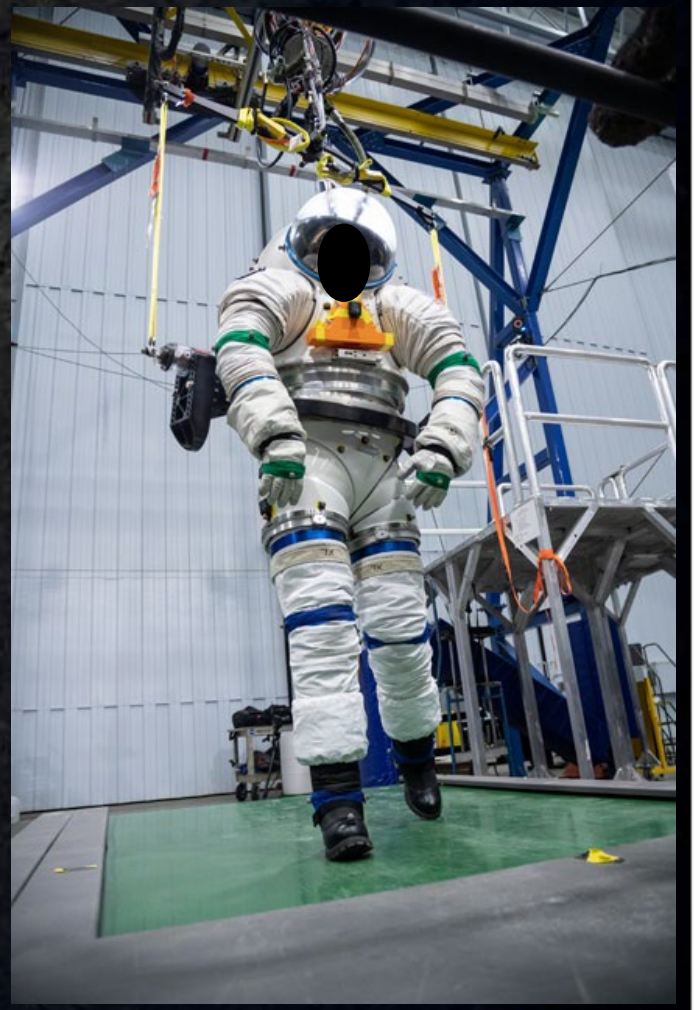
Task: Payload Relocation

- **Performed in Sand Trailer**
  - Varied slope
  - Varied terrain
- **Move weighted bags (30lbs) across trailer for set amounts of time**
- **Functional Tasks:**
  - Walking
  - Lunar Walking - Positive Slope
  - Lunar Walking - Negative Slope
  - Carry
  - Climb up/descend steps (trailer)



Task: Traverse

- **Treadmill walking simulates traversing lunar surface**
  - Varied slope
  - Self selected pace
    - E2E: Instruct to not go too slow, “comfortable” EVA pace
    - SA: time limit to complete distance
- **Distances and slopes determined using realistic lunar traverse paths**



Testing Timelines

♦ DAY 1

♦ **SA BLOCKS:**

- CG_Gimbal settings
- Functional Movements
- PRIMUS
- Object Relocation
  - Slope 0, 30 lbs, rocky
  - Slope 0, 30 lbs, sandy
  - Slope 10, 30 lbs, rocky
  - Slope 10, 30 lbs, sandy
- Task Board Operations
- Incapacitated Crew Rescue Crew Loading

♦ DAY 2

♦ **E2E Block:**

- Lander Platform
- 1500m Traverse
  - Varied negative grades (-5%, -7%, and -10%)
- Geology
  - Slope 0˚
- 500m Traverse
  - 30% grade
- Geology
  - Slope 10˚
- 500m Traverse
  - 20% Grade
- Object Relocation
  - Small and Large Volumes
  - 10lb and 20lb
- 500m Traverse
  - 20% Grade

♦ **BREAK**

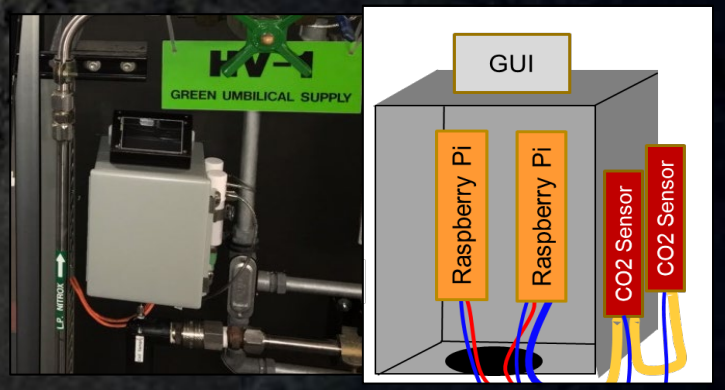
♦ **SA BLOCKS:**

- 2000m Traverse
  - Varied grades (-10% to +30%)
- Geology Rake
- Geology Trench
- Geology Float Sample
- Geology Scoop
- Geology Sample Tagging
- Geology Drive Tube

Collected data: Metabolic Rate & Heart Rate

♦ Metabolic Rate

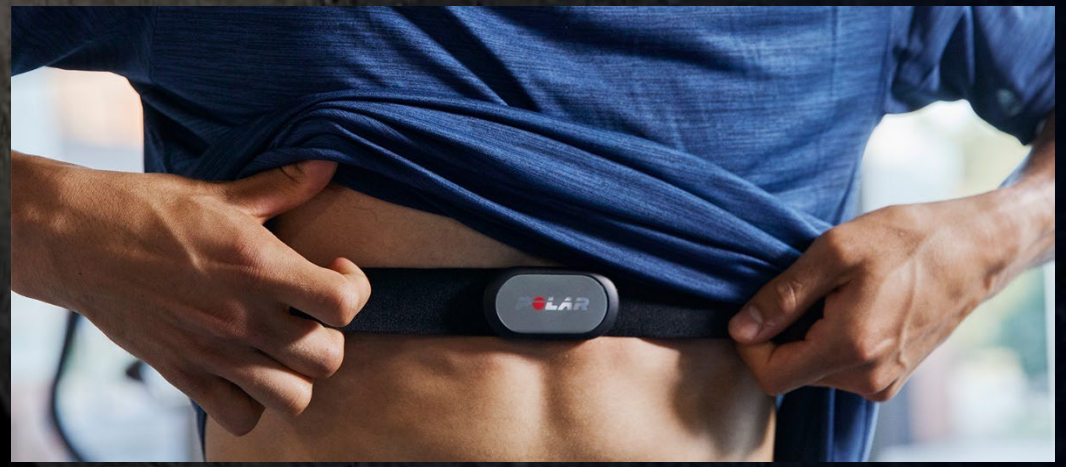
- Calculated using measures of expired carbon dioxide (CO_2)
- Values categorized as:
  - **Low = ≤ 700 BTU/hr**
  - **Medium = 700-1000 BTU/hr**
  - **High = ≥ 1000 BTU/hr**



♦ Heart Rate

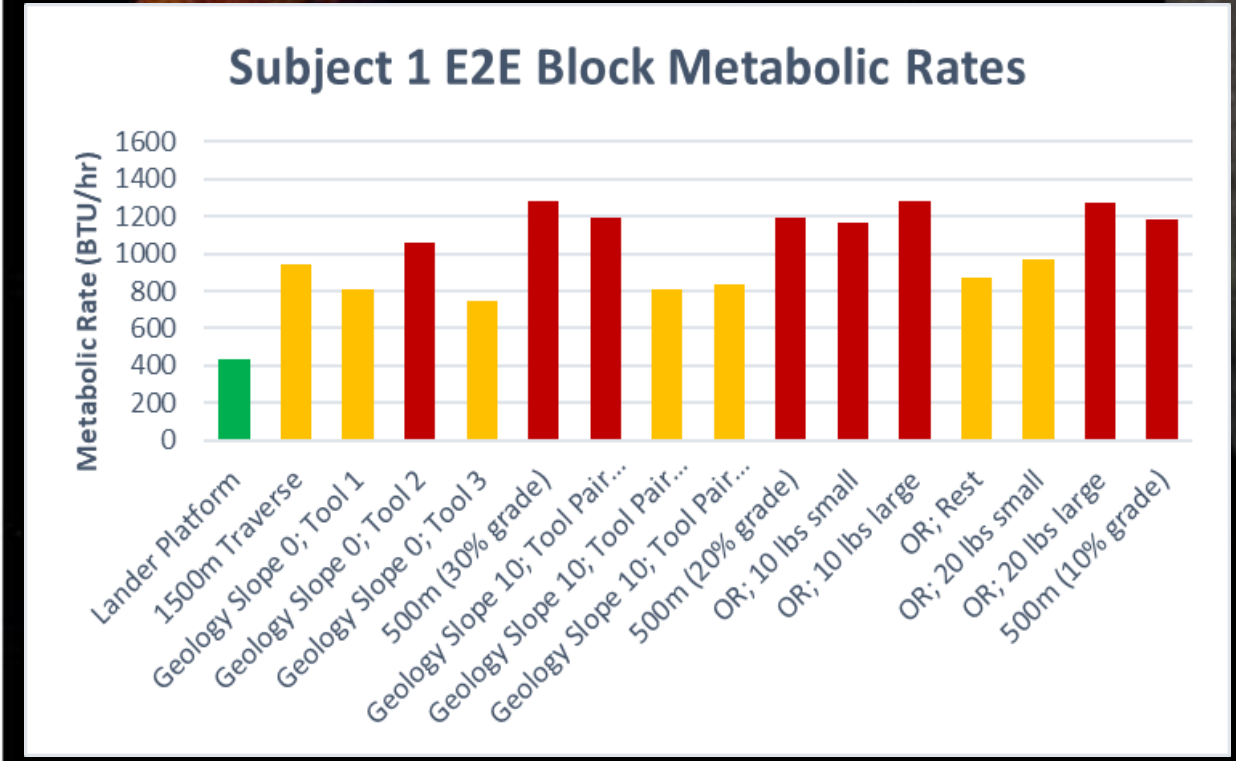
- Polar H10 Heart Rate Monitor
- Values categorized in HR zones as:

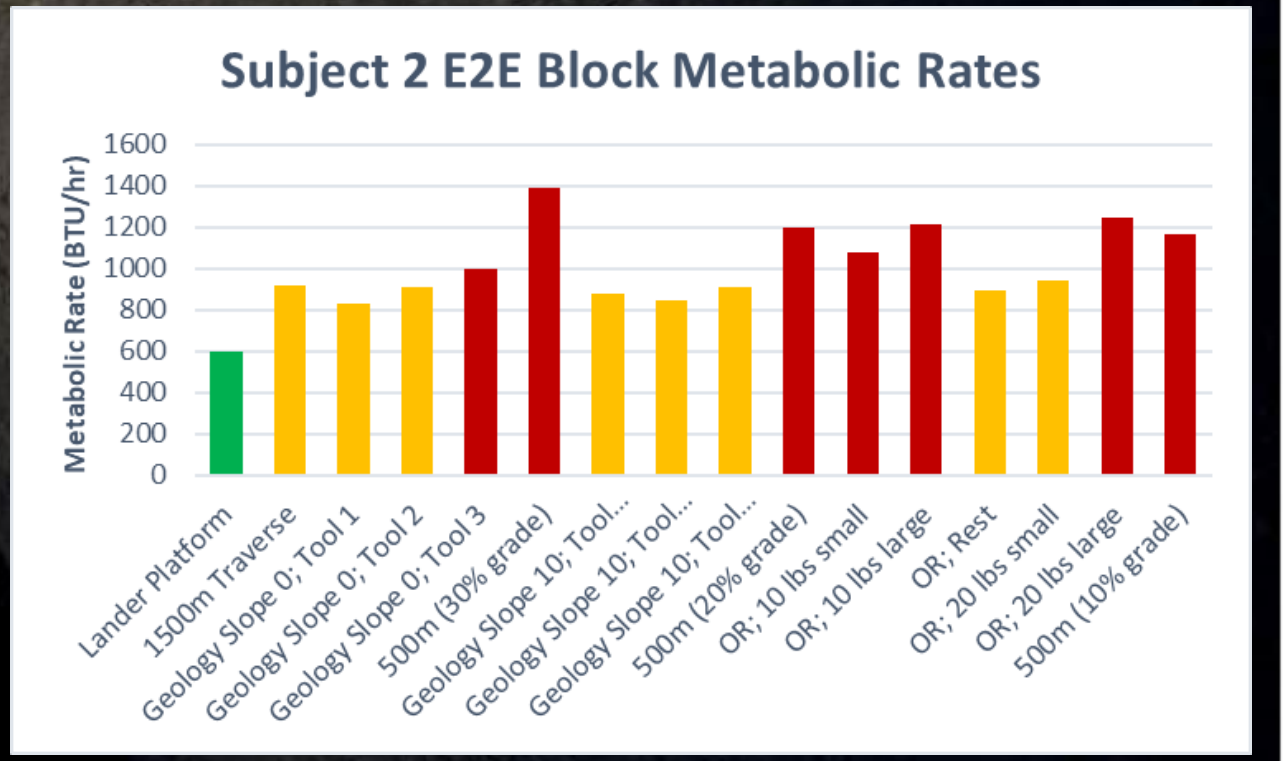
Zone	Intensity	Percentage of HRmax
Zone 1	Very light	50–60%
Zone 2	Light	60–70%
Zone 3	Moderate	70–80%
Zone 4	Hard	80–90%
Zone 5	Maximum	90–100%



Results: Metabolic Rate

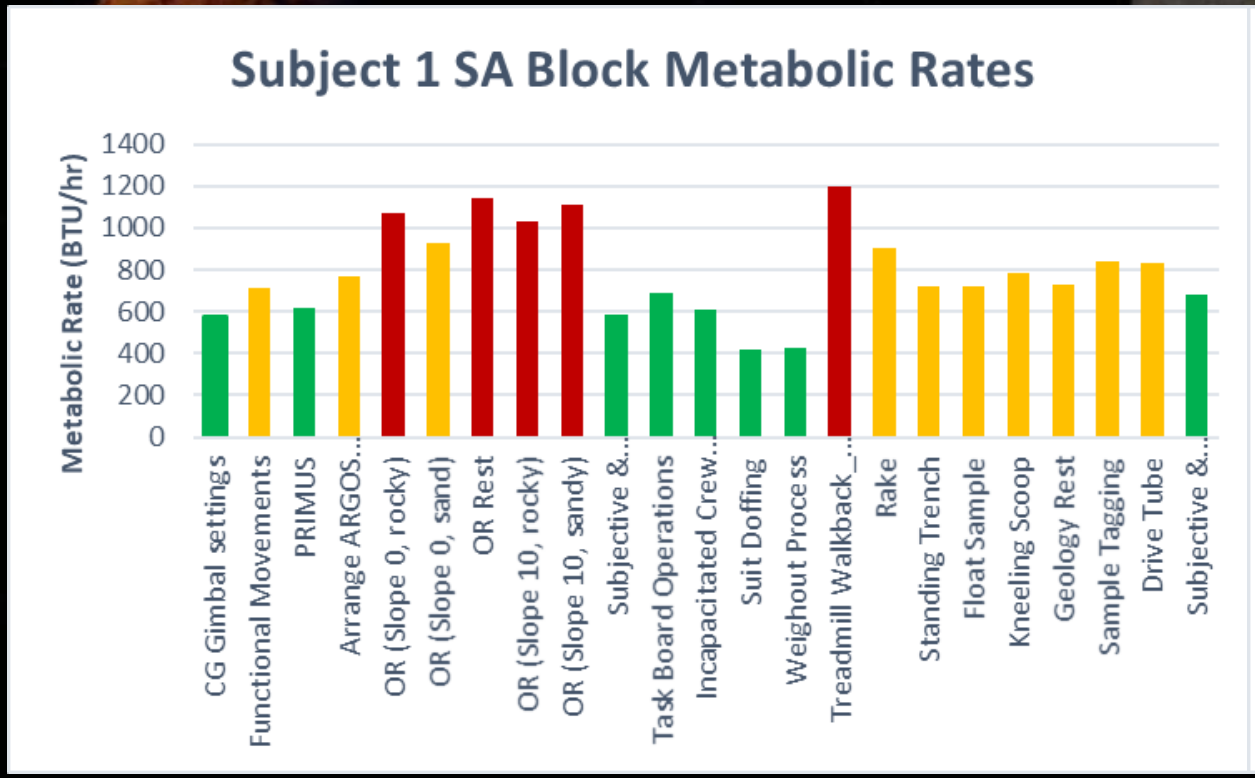
- **E2E Block: 16 total tasks**
  - Low 6%
  - Medium 47%
  - High 47%

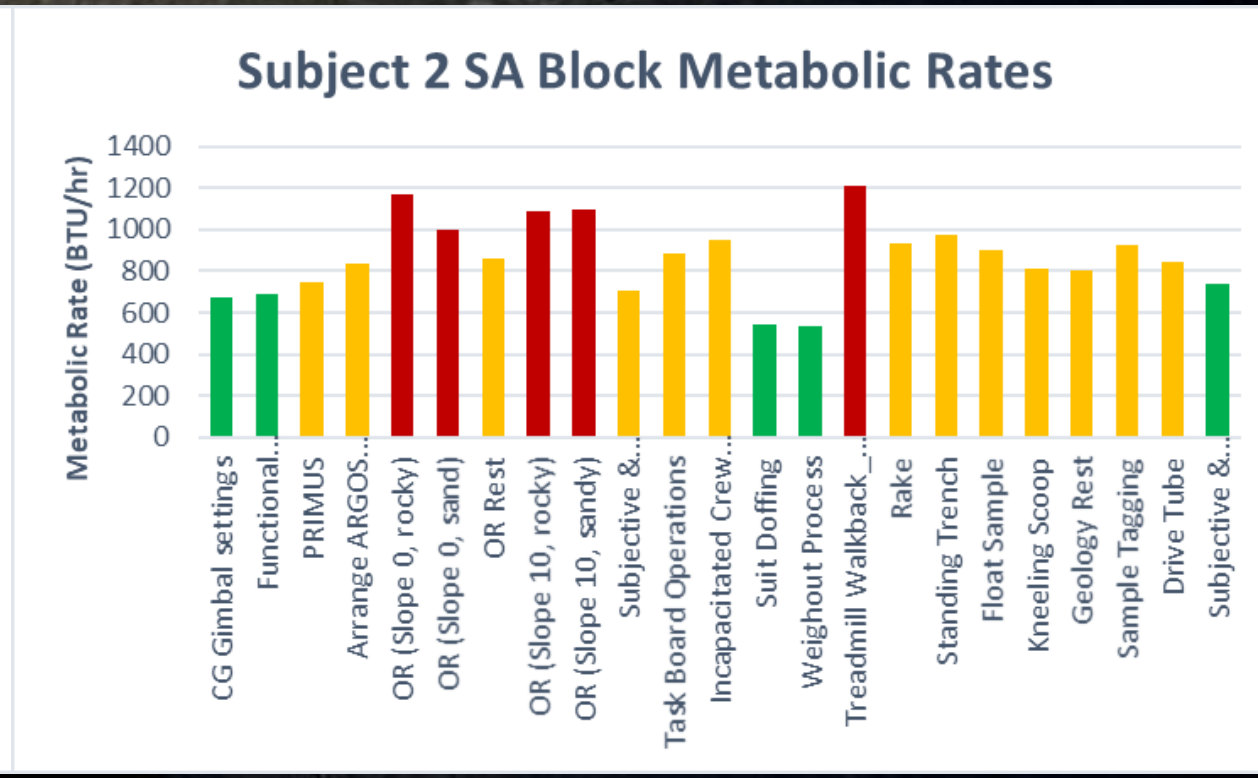




Results: Metabolic Rate

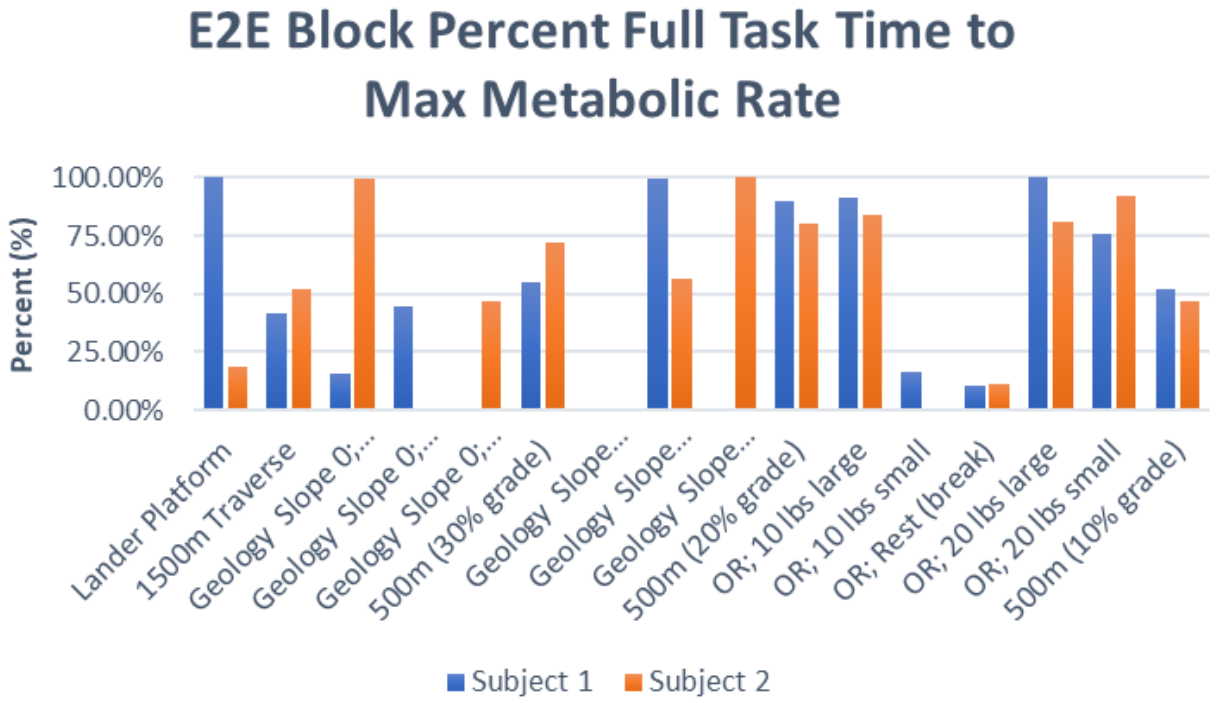
- **SA Block: 23 total tasks**
  - Low 26%
  - Medium 52%
  - High 22%

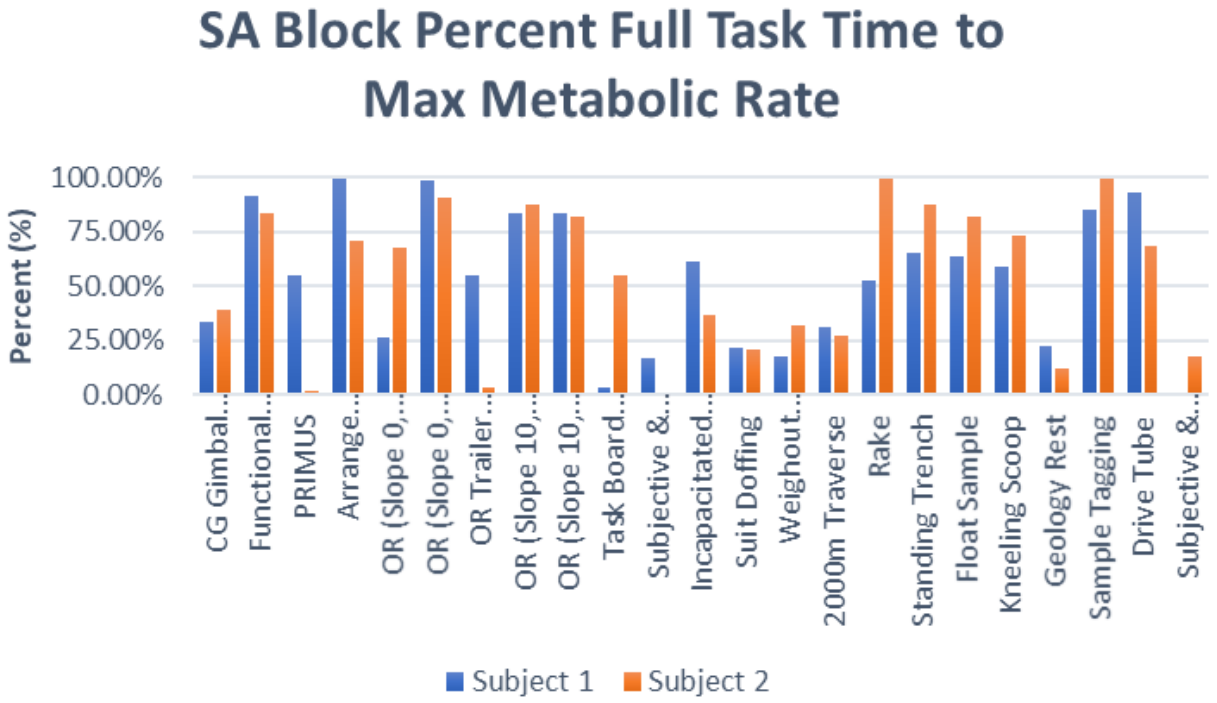




Results: Percent Full Task Time to Max Metabolic Rate

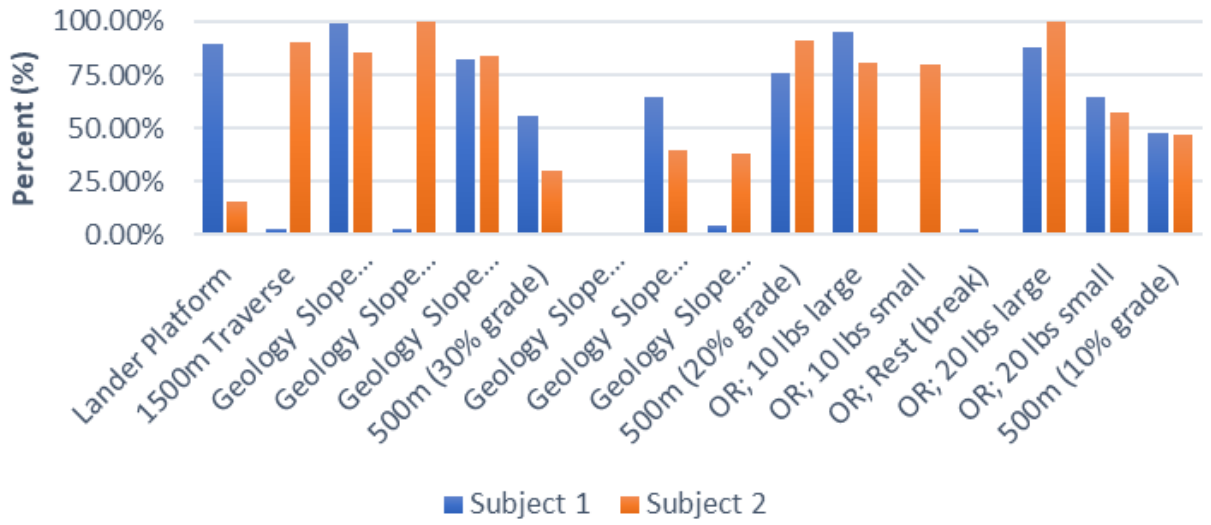
- **Maximum metabolic rate reached during 500m traverse at 30% grade in the E2E block for both subjects**
  - **Subject 1: 1747 BTU/hr**
  - **Subject 2: 1656 BTU/hr**

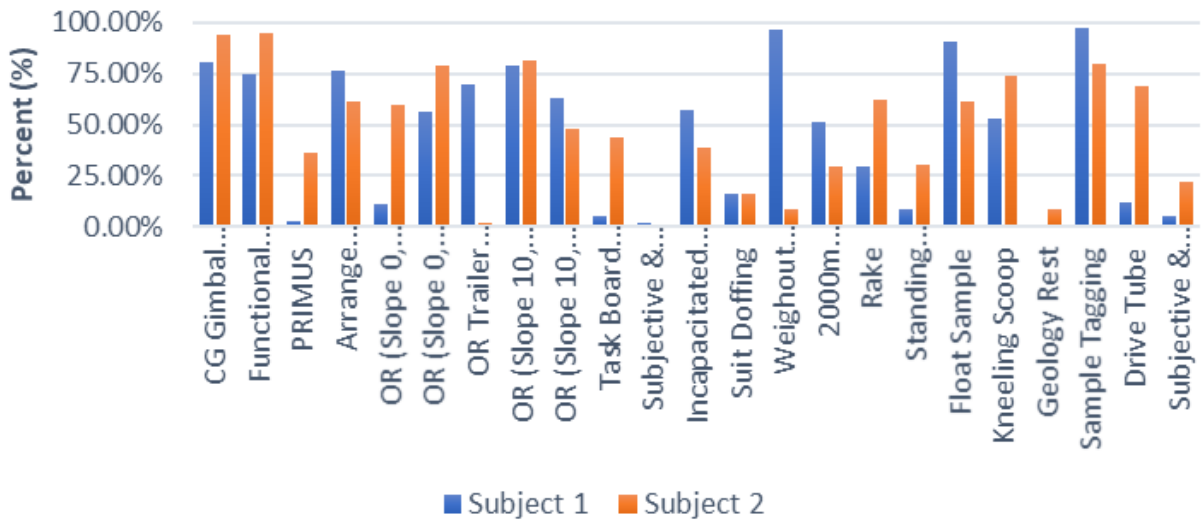




Results: Percent Full Task Time to Max Heart Rate

- **Maximum heart rate reached during 500m traverse at 30% grade in the E2E block for both subjects**
  - Subject 1: **150 BPM**
  - Subject 2: **177 BPM**





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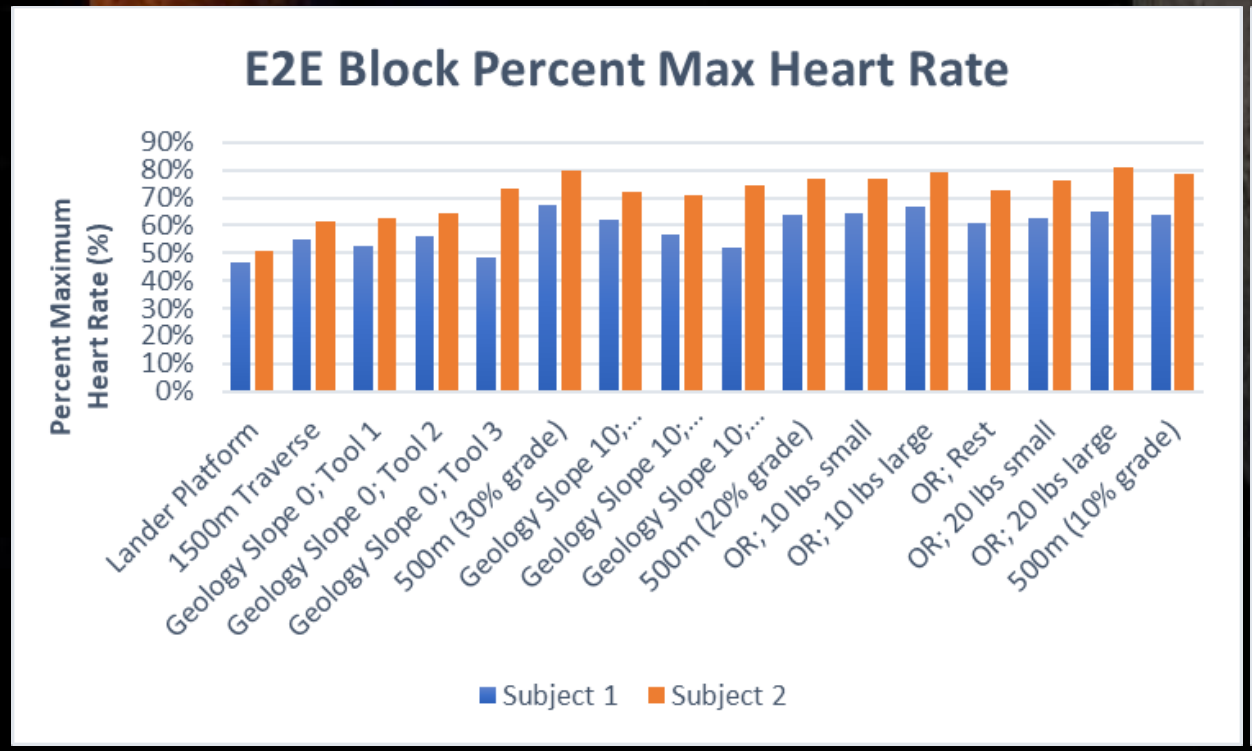

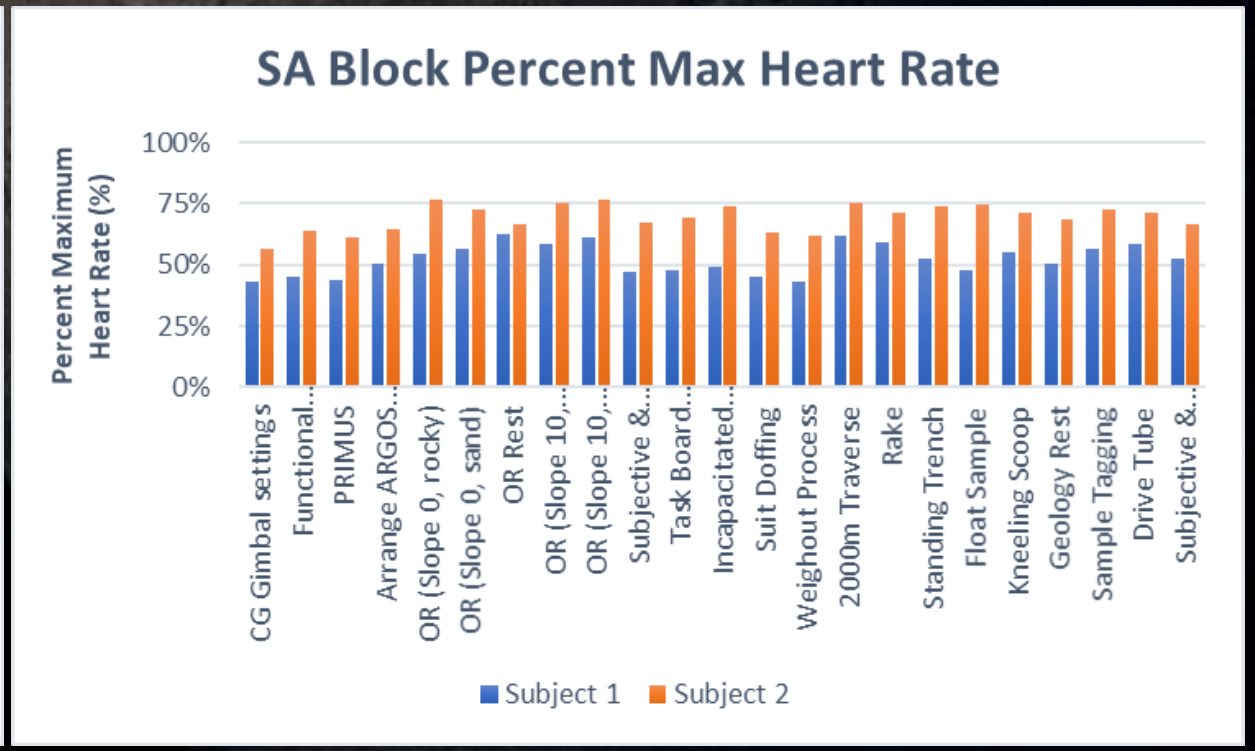

Discussion

- **Understanding the physical demands to complete exploration EVA tasks will be instrumental to the future success of exploration spacesuit designs and missions**
  - Harder tasks that could negatively impact an astronaut's ability to complete an EVA
- **Subjects achieved a plateau HR range and maintained at that level across the full end-to-end EVA**
- **EVA planning must consider which tasks are more physically demanding for suited subjects**
- **Characterizing these tasks is especially important to ensure EVA success on the Lunar surface.**

Next Steps…

- **Further work in this study will be needed to characterize MR**
  - Expand subject pool
  - Testing new suit design(s)
  - Compare findings to testing in other analogs (NBL)

- **Define analog environment "coefficients"**
  - Better comparison of suited environments

- **Use findings to inform**
  - Modeling capabilities
  - EVA planning
  - Training
  - Future suit design capabilities

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Thank you!
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